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RHOMOLO: A Dynamic General Equilibrium Modelling Approach to the Evaluation of the EU's R&D Policies

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Abstract

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Contents

RHOMOLO: A Dynamic General Equilibrium Modelling Approach to the Evaluation of the EU's R&D Policies☆

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Abstract

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Keywords: Economic modelling, R&D, innovation, knowledge spillovers, spatial equilibrium, economic geography.
JEL code: D51, F1, O1, R12, R13, R23, R3, R4.

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1. Introduction

The geographical distribution of the gains from economic integration has been a concern of decision makers since the early beginnings of the European Union. Cohesion policy is the EU's instrument for reducing regional disparities and stimulating the economic development of regions that are lagging behind (European Commission, 2014). EU support to regions is provided as a financial contribution to programmes negotiated with the Member States. The Structural and Cohesion Funds amount to roughly one third of the EU budget, which means that between 0.3% and 0.4% of the EU's GDP is redistributed over Member States and regions through cohesion policy. At the receiving end - for the less developed regions - the inflow of funds can be a very substantial part of regional income even though there is a maximum of about 4% of GDP to the funding received by any Member State in a given year.

Cohesion policy supports a wide range of activities, ranging from the building of motorways to training programmes, such as for instance helping new magistrates to improve their knowledge of EU law. The multitude and diversity of the projects and inter-dependencies between regions make it difficult to evaluate the effects of cohesion policy at any aggregate level. Nevertheless, this is what EU policymakers are required to do in order to be able to compare the returns on different types of investment, taking into account the externalities which would justify making the public investment at the EU level. How the funding assists the regions in increasing their capacity for growth and to what extent the impact spreads across regions are major issues of cohesion policy evaluation, for which a general equilibrium modelling approach with a spatial dimension is required.

In this study we present a spatial computable general equilibrium approach to policy impact assessment. In order to demonstrate the strengths of the approach, the paper takes the example of two broad categories of investment – research, technological development and innovation (RTDI), on the one hand, and infrastructure (INF) on the other – and looks at possible impacts on EU regions. In doing so, it addresses a point made in the 6th cohesion report that, even though the infrastructure connecting the EU15 - the Member States forming the EU before the enlargement in 2004 - had largely been completed, there is still a great need to improve transport links to the EU13 - the thirteen

Member States which joined in the last rounds of EU enlargement. The 6th cohesion report also argues that support to enterprises and R&D in the EU15 should not go at the expense of other types of investment, pointing out that investments in human capital and innovation might be more appropriate for the less developed regions in the EU15.

Running simulations with the 2014-2020 cohesion policy expenditure data for RTDI and INF until 2025, we show how the approach taken in RHOMOLO[1] can help to identify the potential impact of policy interventions at the regional level and the shift of the pattern of the impact between regions and sectors over time. In order to assess the possible impact of investments in RTDI and infrastructure over time, the RHOMOLO model is used in combination with the Commission's QUEST model (Varga and in 't Veld, 2010). The sophisticated dynamics and inter-temporal optimisation in a multi-country setting of QUEST allows for inter-temporal calibration of RHOMOLO with respect to the macro-dynamics of QUEST.

The simulation results presented in this paper highlight the choices that policymakers are facing in the allocation of funds to Member States and to broad categories of investment covering all EU regions, and how the spatial computable general equilibrium approach taken in RHOMOLO can help in identifying their possible implications on regional economies. Ideally, this approach should also help to find combinations of allocations to regions and categories of investment that would make all EU regions better off. However, in view of the complexity of the spatial interactions and the uncertainty surrounding the key parameters of RHOMOLO, this issue remains a promising avenue for future research.

In developing a spatial computable general equilibrium approach, implementing it empirically for the whole EU at the regional level and demonstrating how it is operated, the paper attempts to fill the gap identified in the literature (Broecker *et al.*, 2001; Broecker and Korzhenevych, 2013; Varga, 2015). Conceptually, the closest model to RHOMOLO is CGEurope (Broecker and Korzhenevych, 2013). With respect to empirical implementation, however, there are significant differences and hence complementarities between the two models. Whereas CGEurope is more sophisticated along the spatial dimension,

[1] Regional HOlistic MOdeLO (Brandsma *et al.*, 2015).

RHOMOLO provides a greater sectoral detail. Each of the 267 NUTS2 regional economies is divided into six NACE1 economic sectors. In addition, RHOMOLO also includes labour migration between regional economies. This makes it a comprehensive tool for assessing the impact of the whole of cohesion policy at the regional level, which amounts to roughly 50 billion euro of spending via the EU budget per year.

The approach taken in this study is consistent with the concept of the Geographic Macro and Regional modelling (Varga, 2015). RHOMOLO adds to this literature an inter-regional and inter-sectoral dimension, by modelling industry concentration, agglomeration and dispersion forces endogenously. The RHOMOLO dataset is complete for all NUTS2 regions and consistent with national accounts and international trade data. All key parameter values for each type of policy intervention are either, whenever warranted, econometric estimates are made on the basis of micro- or regional-level data, or taken from the related empirical literature, when due to data limitations econometric estimations are impossible. In RHOMOLO the regional differentiation accounts, for example, for the level of economic development and, in the case of RTDI, also for the distance to the technological frontier in sectors of the economy.

The paper first presents the background and main features of RHOMOLO. Section 3 describes the data that are used for empirical implementation, structural parameter estimation, calibration and sensitivity analysis of the model. Two scenarios are set up in section 4 with simulation results discussed in section 5. Section 6 makes concluding remarks.

2. The RHOMOLO model

The domestic economy (which corresponds to the EU) consists of $R-1$ regions $r = 1, \ldots, R-1$, which are included into M countries $m = 1, \ldots, M$.[2] The rest of the world is introduced in the model as a particular region (indexed by R) and a particular sector (indexed by S). Sector S differs from domestic sectors in that it only has one variety which is exclusively produced in region R. Formally, we have $N_{S,r} = 0$ and $N_{s,R} = 0$ for all r and s; and $N_{S,R} = 1$. The foreign variety of final good is used as the numéraire.

[2] See Brandsma *et al.* (2015) for a formal description of the key mechanisms in the RHOMOLO model.

The final (and intermediate) goods sectors include $s = 1, \ldots, S$ different economic industries in which firms operate under monopolistic competition à la Dixit and Stiglitz (1977). Each firm produces a differentiated variety, which is considered as an imperfect substitute to other varieties by households and firms. Goods are either consumed by households or used by other firms as intermediate inputs or as investment goods. The number of firms in sector s and region r, denoted by $N_{s,r}$, is large enough so that strategic interactions between firms is negligible. The number of firms in each region is endogenous and to a large extent determines the spatial distribution of economic activity.

Trade between (and within) regions is costly, implying that the shipping of goods between (and within) regions entails transport costs which are assumed to be of the iceberg type, with $\tau_{s,r,q} > 1$ representing the quantity of sector's s goods which needs to be sent from region r in order to have one unit arriving in region q (Krugman, 1991, see). Transport costs are assumed to be identical across varieties but specific to sectors and trading partners (regions). They are related to the distance separating regions r and q but can also depend on other factors, such as transport infrastructure or national borders. Finally, transport costs can be asymmetric (i.e. $\tau_{s,r,q}$ may differ from $\tau_{s,q,r}$). They are also assumed to be positive within a given region (i.e. $\tau_{s,r,r} \neq 1$) which captures, among others, the distance between customers and firms within the region.

R&D is modelled as one additional sector of the economy producing innovation. The national R&D sector sells R&D services to local final and intermediate goods firms within the same country and uses regional input. Hence, there are M national R&D sectors which produce new knowledge using a bundle of high skill labour from the different regions of the country. The demand for R&D services depends on the relative unit price of R&D with respect to unit prices of other inputs and output.

The production (and purchase) of R&D services produces a positive externality to all the sectors in the country. The production process of R&D services features learning by doing, as labour productivity is positively related to the existing stock of R&D. The knowledge production function displays constant returns to scale and prefect competition. Government can affect innovative activity through taxes and/or subsidies. In addition, the supply of high skill labour determines the innovation capacity of the R&D sector.

The wage of high skill workers employed in the R&D sector is equalised across regions in a country and there is imperfect substitution between high skill R&D workers in a region (earning the national R&D wage) and high skill workers in the others sectors of the regional economy, whose wage is determined regionally. Each national sector buys national R&D services at the same price, there are no trade costs for R&D services, which are traded among all regions within countries, but not internationally.

In RHOMOLO there are international technological spillovers in the sense that the national R&D sector absorbs part of the technology produced in the other $M-1$ countries, which yields international knowledge spillovers as a function of the stock of accumulated knowledge in other countries. In other words, together with labour, material and capital service inputs, the production functions of each sector display a total factor productivity (TFP) parameter, which shifts the production function depending on the stock of R&D.

Each region is inhabited by H_r households, which are mobile between regions. They partly determine the size of the regional market.[3] The income of households consists of labour revenue (wages), capital revenue and government transfers. It is used to consume final goods, pay taxes and accumulate savings.

Finally, in each country there is a public sector, which levies taxes on consumption and on the income of local households. It provides public goods in the form of public capital which is necessary for the operation of firms. It also subsidises the private sector, including the production of R&D and innovation, and influences the capacity of the educational system to produce human capital.

The detailed regional and sectoral dimensions of RHOMOLO imply that the number of (non-linear) equations to be solved simultaneously is relatively high. Therefore, in order to keep the model manageable from a computation point of view, its dynamics are kept relatively simple. Three types of factors (physical capital, human capital and knowledge capital) as well as several types of assets are accumulated between periods. Agents are assumed to save a constant fraction of their income in each period and form their expectations based only on the current and past states of the economy. The dynamics of the model is then described as in a standard Solow model, i.e. a sequence of short-run

[3] Labour mobility is introduced through a labour market module which extends this core version of the model with a more sophisticated specification of the labour market. This is described in Brandsma *et al.* (2014).

equilibria that are related to each other through the build-up of physical and human capital stocks.

RHOMOLO contains several endogenous agglomeration and dispersion forces affecting the location choices of firms (see Di Comite and Kancs, 2014, for a detailed description of endogenous location in RHOMOLO). Three effects drive the mechanics of endogenous agglomeration and dispersion of economic agents in RHOMOLO: the *market access effect*, the *price index effect* and the *market crowding effect*. The *market access effect* captures the fact that, everything else equal, in presence of mentioned endogenous agglomeration and dispersion forces firms in large/central regions would have higher profits than firms in small/peripheral regions, and hence the tendency of firms to locate their production in large/central regions and export to small/peripheral regions. The *price index effect* captures the impact of firms' location and trade costs on the cost of living of workers, and the cost of intermediate inputs for producers of final demand goods. The *market crowding effect* captures the fact that, because of higher competition on input and output markets, firms may prefer to locate in small/peripheral regions with fewer competitors.

RHOMOLO contains three endogenous location mechanisms that bring the agglomeration and dispersion of firms and workers about: the mobility of capital, the mobility of labour, and vertical linkages. Following the mobile capital framework of Martin and Rogers (1995), we assume that capital is mobile between regions; and the mobile capital repatriates all of its earnings to the households in its region of origin. Following the mobile labour framework of Krugman (1991), we assume that workers are spatially mobile (though the mobility is not perfect); mobile workers not only produce in the region where they settle (as the mobile capital does), but they also spend their income there; workers' migration is governed by differences in the expected income, and differences in the costs of living between regions (the mobility of capital is driven solely by differences in the nominal rates of return).[4] Following the vertical linkage framework of Venables (1996), we assume that, in addition to the primary factors, firms use intermediate inputs in the production process; and, similarly to final goods consumers, firms value the variety of intermediate inputs, the trade of which is costly.

[4]In the model also the regional unemployment rates enter the migration problem of workers.

3. Data and empirical implementation

3.1. Dimensions of RHOMOLO

RHOMOLO covers 267 NUTS2 regions in the EU27, which are disaggregated into six NACE Rev. 1.1 sectors plus R&D sector (see Table 1 and Figure 1, respectively).[5] The regional and sectoral disaggregation implies considerable data needs. In particular, for the empirical implementation of the RHOMOLO model, data for all exogenous and endogenous variables at regional and sectoral level for the base year (2007) and numerical values for all behavioural parameters are required.

Table 1: Sectoral disaggregation of the RHOMOLO model

NACE code	Sector description
AB	Agriculture, hunting and forestry
C	Construction
DEF	Mining, quarrying, manufacturing, energy
GHI	Wholesale & retail trade, vehicle repair, motorcycles, hotels, restaurants, transport, communications
JK	Financial intermediation, real estate and business services
LMNOP	Non-market services

Source: Authors' aggregation based on the EUROSTAT (2003) NACE Rev. 1.1 classification. R&D sector is separated out from the standard NACE group JK.

The base year (2007) data are compiled in the form of regional Social Accounting Matrices (SAMs) (see Potters *et al.*, 2013, for details). For the construction of national SAMs, data are taken from the World Input Output Database (WIOD) project and the Global Trade Analysis Project (GTAP). The WIOD database consists of International Input-Output tables, International and National Supply and Use tables, National Input-Output tables, and Socio-Economic and Environmental Accounts, covering all EU27 countries and the rest of the world for the period from 1995 to 2009. An attractive feature of the WIOD data is that an attempt is made to identify and take out re-exports

[5]The simulations presented in this paper were performed with the RHOMOLO model, which was calibrated to 2007 base year data. In the next updates of the base year RHOMOLO will be extended to include also Croatia. See https://ec.europa.eu/jrc/rhomolo for the latest version of the RHOMOLO model and base year data.

before calculating the total value of exports. Generally, the WIOD data are available for 59 NACE Rev. 1.1 sectors, which for the purpose of the present study are aggregated into the six macro-sectors used in RHOMOLO (see Table 1). The SAMs are constructed at the national level, based on the Supply and Use tables, and then regionalised while keeping national aggregates, such as, value added, trade, consumption and employment, as constraints.

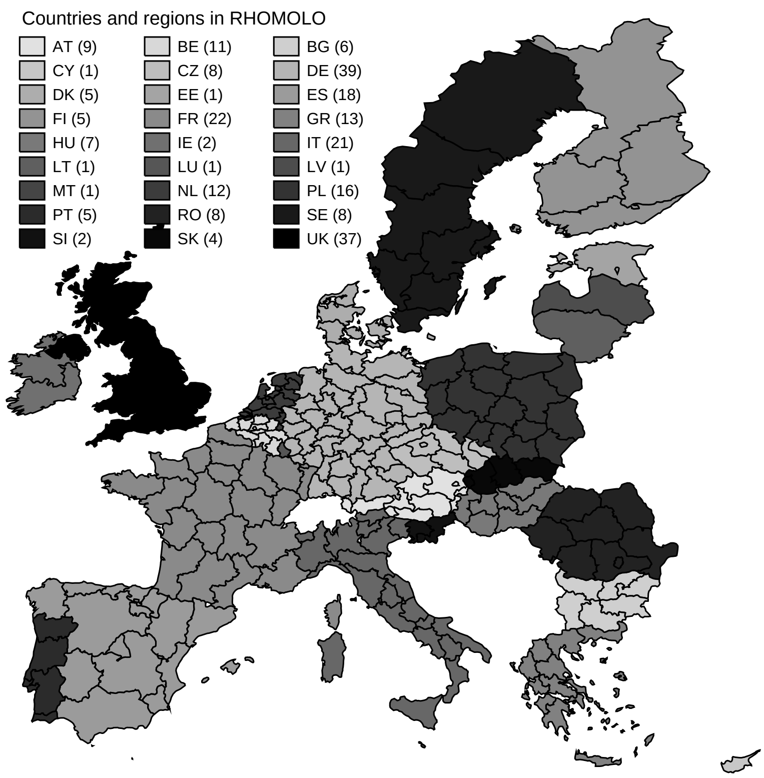

Figure 1: Spatial disaggregation of the RHOMOLO model. Notes: The number of NUTS2 regions in each country are in parentheses (in total these numbers sum up to 267).

3.2. Data for inter-regional variables

Inter-regional labour migration patterns are captured in RHOMOLO by data on net changes in the regional labour force (see Brandsma *et al.*, 2014, for details). Using these data, the relocation of workers between any two regions is modelled as a function of expected income and distance. For the estimation of migration elasticities data are required on labour migration, regional GDP and unemployment. EUROSTAT's Regional Migration Statistics provides data on migration within Member States. In order to complete the regional migration matrix, national totals are brought in line with OECD data on migration in OECD countries, providing data on migration flows between countries. The Household Income and Active Population data are extracted from EUROSTAT. Together with data on unemployment and wages, which are extracted from the labour force survey, the constructed data on of inter-regional migration flows provide the necessary input to the estimation, calibration and modelling of labour market and migration features in the RHOMOLO model.

Inter-regional trade flows are estimated using detailed inter-regional transport and freight data from Thissen *et al.* (2013, 2014). These data are aligned with the available macro-data: the distribution of production and consumption over the EU regions and the national SAMs to ensure consistency with the rest of the RHOMOLO database. The regionalised SAMs were used for the construction of the regional production and consumption constraints. Inter-regional trade costs come from the TRANSTOOLS database, which add up to the country level trade and transportation margins calculated from WIOD.

3.3. Data for inter-temporal variables

Knowledge capital enters RHOMOLO through region-specific R&D intensities (expenditures on R&D divided by GDP), which are available at the national and regional level from the EUROSTAT's Science and Technology Indicators database. Whereas R&D data by sector are available at the national level, comparable data are not available at the regional level for most of the countries. EUROSTAT distinguishes four sectors of performance – governments, higher education institutions, business sector and private non-profit organisations, which however do not correspond to the six macro-sectors of RHOMOLO. Given the sectoral aggregation adopted in RHOMOLO (see Table 1), all expenditures on R&D outside the business sector fall under non-market services. The sectoral disaggregation is made by using the gross fixed capital formation by NACE sector calculated at the regional level.[6]

[6]Currently undergoing extension of the innovation module in RHOMOLO with additional features beyond R&D includes two elements. First, European Commission-based regional patent statistics and citations offer valuable information on technological proximity across regions in Europe. Second, the inclusion of the micro-estimated data from the Community Innovation Survey is used to identify a broader set of regional innovation features – closely related to the policy domains identified in the current taxonomy of cohesion policy investments.

The regional stock of human capital is proxied in the RHOMOLO database by 3 different levels of education: low skill (isced0_2), medium skill (isced3_4), and high skill (isced5_6). Wages are differentiated on the basis of the corresponding categories of education levels to account for the decision of households to spend their time on education. Data for this are available in the Labour Force Survey (LFS) and the EU KLEMS database.

Data on the regional stock of physical capital are constructed using the Perpetual Inventory Method (PIM). This approach starts with an estimate of the initial stock by country and industry, regionalised by the share in gross value added (GVA) in 1995 and calculates the final capital stock by region and by industry in 2007 by adding the yearly capital investments and making assumptions on depreciation. The following data can be estimated: gross fixed capital formation by sector at the NUTS2 level in current prices for the years 1995-2010; price deflators for conversion into constant prices; initial stocks for calculating the net capital stocks for each year applying the PIM from the EU KLEMS database. These data are available at the national level, which are regionalised by the GVA share; depreciation rates are calculated by weighing the average service life of each of the six types of assets for each country (according to the ESA95 classification).

3.4. Model parameters

In order to parameterise the RHOMOLO model, whenever possible, all key structural parameters are estimated econometrically; others – for which no sufficient data are available – are drawn from the literature (Okagawa and Ban, 2008). For example, all parameters related to the inter-regional labour migration are estimated in a panel data setting for each country separately (Brandsma *et al.*, 2014; Persyn *et al.*, 2014). Similarly, all parameters related to the elasticities of substitution both on the consumer and on the producer side are being estimated econometrically. For the purpose of simulations presented in this paper, which is focussed on the spatial pattern of the effects rather than the sectoral, the elasticities of substitution are the same for all sectors and regions.

Finally, as usual in spatial computable general equilibrium models, all shift and share parameters are calibrated to reproduce the base year (2007) data in the SAMs. In order to determine the sensitivity of simulation results with respect to the implemented parameters in RHOMOLO, we perform extensive sensitivity analysis and robustness checks. Among others, the sensitivity analysis allows us to establish confidence intervals (in addition to the simulated point estimates) for RHOMOLO's simulation results.

4. Cohesion policy and scenario construction

4.1. European Cohesion Policy

Cohesion policy for 2014-2020 focuses on the "Europe 2020" objectives and mainly target growth and jobs. The total cohesion policy expenditure of 342 billion euro is divided over 123 lines of expenditure in the 2014-2020 programming period. A closer inspection of the 123 expenditure categories suggests that modelling of each expenditure category separately is hardly feasible given the multi-interpretable and often overlapping description of the lines of expenditure.[7] Therefore, for the purpose of simulations presented in this paper, the 123 expenditure categories are regrouped into five broad categories, which match five different parameters in the model. Table 2 provides an overview of the expenditures per type of region and aggregate expenditure category. The last column in Table 2 shows that around two thirds (68%) of the European Cohesion Policy (ECP) funds are reserved for the Less Developed Regions. The category 'Infrastructure' covers almost half of all ECP funds (49%).

4.2. Research and technological development scenario

The construction of the research and technological development scenario, which is simulated in RHOMOLO, involves the following steps: (i) aggregating all relevant ECP expenditure lines into one broad RTDI category; (ii) specifying the parameter or set of parameters through which the policy shock will be applied in RHOMOLO; (iii) estimating the size of the shock in each region and the pattern by which it is spread over time; and (iv) (if necessary) making

[7]This is true for all five broad categories, but in particular for interventions categorised under RTDI. Some of the 123 expenditure lines can be associated with improving the public research infrastructure; some others with augmenting the regional knowledge stock as such or with creating incentives for private firms to invest more in R&D. A more precise delineation within the RTDI category would not be of much help either, because the stages of research, development, diffusion and use are known to be highly interdependent.

Table 2: Breakdown of Cohesion Policy expenditures for 2014-2020, Million Euro.

Type of region	No	RTDI	IND	INF	HC	A	Total	Share
Less Developed Regions	65	25250	27127	129128	38408	12162	232075	0.68
Transition Regions	51	5772	6218	14339	10201	1585	38115	0.11
More Developed Regions	151	10916	9101	24167	24196	2954	71335	0.21
Total	267	41938	42447	167634	72805	16701	341525	1.00
% of total ECP		0.12	0.12	0.49	0.21	0.05	1.00	

Source: European Commission (2014). Notes: No: number of regions per category of region types (267 = total number of regions in RHOMOLO); INF: Infrastructure; HC: Human Capital; RTDI: Research, Technological Development and Innovation, IND: Industry and Services; A: Technical Assistance.

further adjustments to correct for any known deficiencies of the model vis-à-vis the scenario at hand.

As shown in Table 2, for the 2014-2020 programming period, almost 42 billion euro have been allocated to those lines of expenditure that can be associated with support to research, technological development and innovation (RTDI).[8] This corresponds to around 12% of the total ECP expenditures. Around 60% of the total RTDI expenditures (25 billion euro) is to be allocated to the less developed regions (see Table 2).

In a second step, the relevant parameters, through which the RTDI policy shock will be applied in RHOMOLO, is specified. The nested production structure of RHOMOLO contains many different entries for TFP shocks. They are activated in a constrained way in the present simulation, which applies the same TFP shock to all sectors in the region.[9] For the purpose of the present exercise, an increase in productive public capital and R&D sector's productivity improvements are the two main conduits for RTDI support.[10]

In a third step, the size of the shock in each region and the pattern by which it is spread over time is estimated econometrically. For the purpose of

[8]Note that the split between the support to RTDI and human capital development is not very clear-cut. There are also overlaps with aid to the private sector provided under cohesion policy, a residual category which is as large as the RTDI part itself, and with the separate category of technical assistance.

[9]This simplification means that the link between publicly funded research and the productivity effects of cohesion policy interventions is not fully explored in the simulations. In particular, the contribution of the structural and investment funds to increasing the absorption and innovation capacity at the regional level would deserve greater attention in future evaluations of cohesion policy.

[10]See Di Comite and Kancs (2015) for a discussion of alternative approaches for implementing and modelling R&D policies.

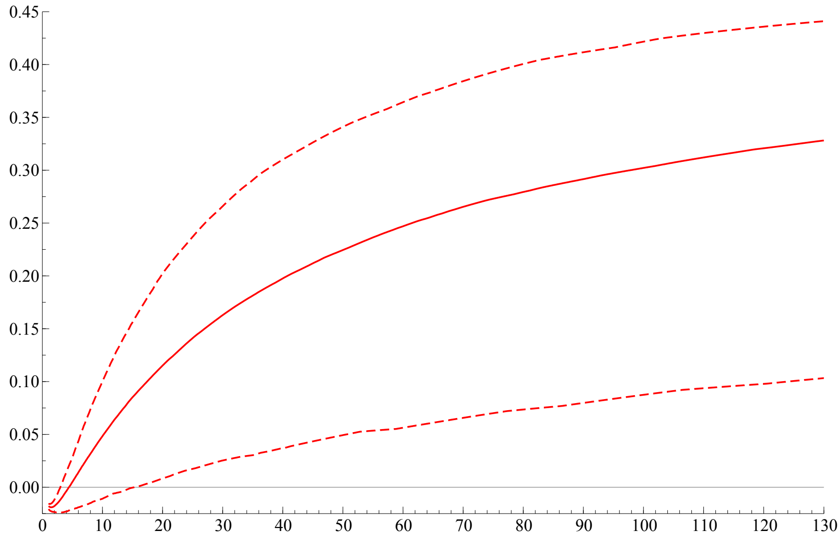

Figure 2: **RTDI scenario construction**: Elasticity of of TFP [Y-axis] with respect to R&D intensity [X-axis]. Dashed lines: bootstrapped 90 % confidence interval based on 1000 replications. Source: Authors' estimations based on Kancs and Siliverstovs (2015).

this study, these estimates are readily available from Kancs and Siliverstovs (2015). The estimates of Kancs and Siliverstovs (2015) suggest a plausible range of elasticities between 0.20 and 0.30 (see Figure 2).[11] This is close to the estimates used also in the QUEST model (Mc Morrow and Roeger, 2009) and RHOMOLO (Di Comite *et al.*, 2015), and are therefore adopted in the present simulations. In order to ensure robustness of the simulation results, extensive sensitivity analysis are performed for a plausible range of all R&D parameters.

The RTDI scenario is summarised in Figure 3.[12] The middle panel in Figure 3 represents the exogenous policy shock used as input in RHOMOLO simulations. The left and the right panels in Figure 3 are reported only for background information, and for a better understanding of differences between regions.

The left panel reports the ECP expenditure on RTDI in million euro from Table 2. Applying the econometrically estimated elasticities, the information contained in the left map is transformed into region-specific productivity im-

[11]Firm level studies have estimated the size of productivity elasticity associated with R&D investment ranging from 0.01 to 0.32, and the rate of return to R&D investment between 8.0 and 170.0 percent (see Mairesse and Sassenou, 1991; Griliches, 2000; Mairesse and Mohnen, 2001, for surveys).

[12]For further details and assumptions of the RTDI scenario construction see Di Comite *et al.* (2015).

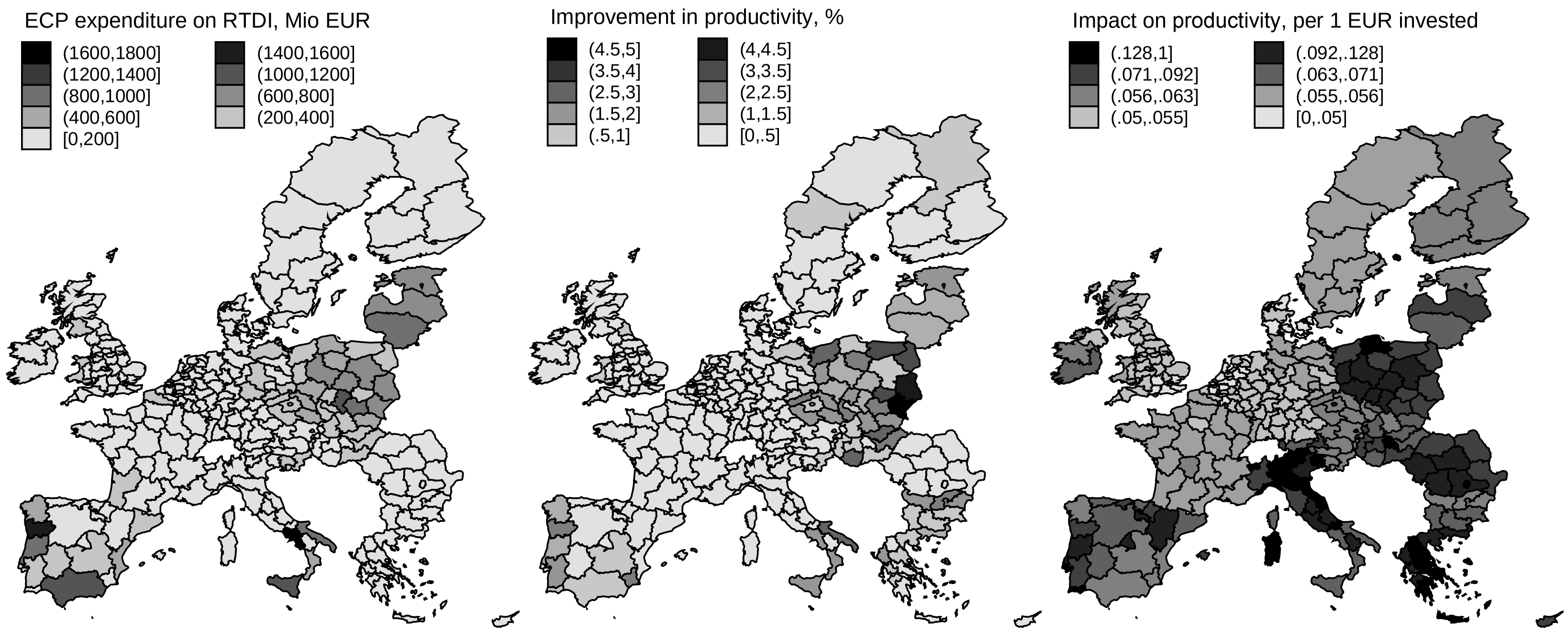

Figure 3: **RTDI scenario construction** (exogenous policy input into simulations). Left panel: EU Cohesion Policy's (ECP) expenditure on RTDI in 2014-2020, Million EUR. Middle panel: Estimated improvement in regions' productivity due to the ECP's investments in RTDI in 2014-2020, changes in percent. Right panel: Estimated marginal improvement in regions' accessibility due to the ECP's investments in RTDI in 2014-2020 per 1 Euro of investment. Middle panel represents the policy shock used as input in model simulations, left and right panels are reported only for background information. Source: Authors' estimations based on European Commission, DG REGIO (2013) data.

provements (middle map). Figure 3 shows a clear correlation between the left and middle maps. Any differences between the two maps can be attributed to spatial knowledge spillovers.

The right map is another way to express the estimated productivity impact of RTDI expenditure – here it is expressed per one euro invested. The right map shows a very different pattern from the left and middle maps, because of spatial knowledge spillovers, the lagging behind regions (mainly in South and East Europe) benefit more than proportionally from RTDI policies. A visible outlier from this general pattern is North Italy, which is both relatively well developed (in terms of technology) and has a high productivity multiplier in the right panel. This result may be driven, for example, by interactions of spatial knowledge spillovers, absorptive capacity and investments in RTDI.

4.3. Transport infrastructure scenario

In order to compare the pattern of regional impacts of RTDI with that of a different category of expenditure, the results of a transport infrastructure scenario are presented in parallel. In a first step an aggregate measure of the total ECP expenditure on *transport infrastructure* is constructed for each region. For this purpose, all policy instruments directly affecting transport infrastructure are aggregated into the total "INF expenditures" per region (see Table 4). No weights are applied at this stage of aggregation, although the literature (European Commission, 2011) suggests that there could be substantial differences in the expected impact per expenditure category.[13]

Next, the spatial dimension of the ECP transport infrastructure investment is approximated based on the region-specific expenditures calculated in step 1. Given that information on region–pair–specific transport cost reductions is not available, region-specific expenditures are converted into region-pair-specific expenditures. The spatial dimension is important because transport infrastructure improvements affect not only the region where the money is

[13] For the purpose of simulations presented in the paper, all infrastructure expenditures are aggregated into one category and consequently modelled uniformly as transport infrastructure improvements. In reality, not all ECP expenditures are designed and implemented to improve transport infrastructure, but the dividing lines are difficult to maintain when looking at the actual expenditures across NUTS2 regions. By far the largest part of the ECP infrastructure expenditures overall, however, is allocated to transport infrastructure (78.1%) (European Commission, 2014).

spent but also all other regions with which it trades. Following Kancs (2013), the adopted bilateral transformation of transport infrastructure investments accounts both for the intensity of the ECP expenditure and for the proximity of regions where the investment takes place. In such a way it introduces a spatial structure (economic geography) in the bilateral measure of transport infrastructure investment by weighting the proximity of regions, implying that the further away are the trading regions (trade is more costly), the less weight will be attributed to the transport infrastructure improvements between the two regions. The weighting implies that the further away are the two regions, the lower impact will a fixed amount of expenditure have (1 km of road can be improved much more than 10 km of road by the same amount of expenditure).

In a third step, INF_{od}, which is a bilateral measure of expenditure in millions of euros, is transformed into changes in bilateral trade costs between regions, which are measured as a share of trade value. This is done by pre-multiplying the bilateral measure of transport infrastructure investments, INF_{od}, by an elasticity measuring the effectiveness of transport infrastructure investments. The elasticity of trade costs with respect to the quality of infrastructure is retrieved from studies on TEN-T infrastructure (European Commission, 2009), because no comparable elasticities are available for ECP investments in transport infrastructure. These elasticities are of the same order of magnitude as those estimated in the literature for other countries. For example, according to the estimates of Francois *et al.* (2009), the elasticity of trade costs with respect to the quality of infrastructure is in the range of -0.02 to 0.60 (see Figure 4, where the elasticities of trade costs are plotted against GDP per capita for countries at different stages of economic development: from developing (left) to developed (right) countries).

The elasticities reported in Figure 4 suggest that the importance of transport infrastructure with respect to trade costs is decreasing in the level of GDP per capita, implying that the marginal impact of an additional unit of investment in public infrastructure in more developed countries/regions (with more developed infrastructure) is smaller than in less developed countries/regions (with less developed infrastructure). The inverse relationship between the elasticity of trade costs with respect to the quality of infrastructure and the GDP per capita suggests to use region-specific elasticities depending on regional GDP: higher

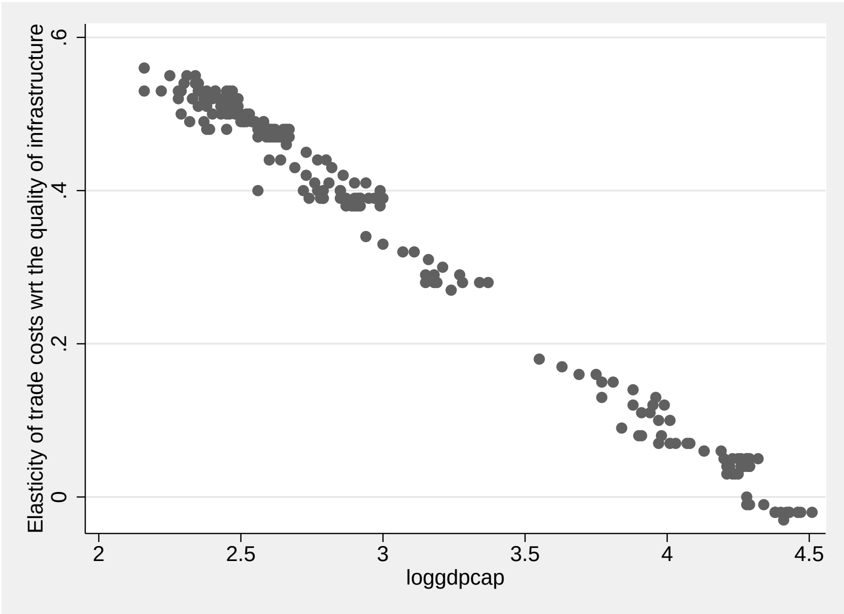

Figure 4: **INF scenario construction**: Elasticity of trade costs with respect to the quality of infrastructure [Y-axis] and log of per capita GDP (2010 EUR) [X-axis]. Source: Authors' estimations based on Francois *et al.* (2009).

for less developed regions, and lower for more developed regions. This is left to future research.

As a result, a transport infrastructure scenario of the ECP investments is obtained that can be readily implemented in RHOMOLO. The constructed scenario is summarised in Figure 5; the left panel shows the expenditure in million euros, the total impact on accessibility is shown in the middle panel of Figure 5. The right panel maps the marginal impact on accessibility, which is calculated as changes in regions' accessibility per euro of cohesion policy investment.

The left and middle panels in Figure 5 show very similar patterns. The right panel in Figure 5 shows that the same investment in transport infrastructure has a larger marginal impact in the more developed regions (dark shaded regions) than in the less developed regions (light shaded regions). Figure 5 confirms that transport cost reductions in the less developed regions have an impact on the accessibility of the transition regions and the more developed regions. Even if there would be zero investment in the more developed regions, they still would benefit from improved access to markets in the less developed regions, making their marginal impact per euro invested obviously much higher

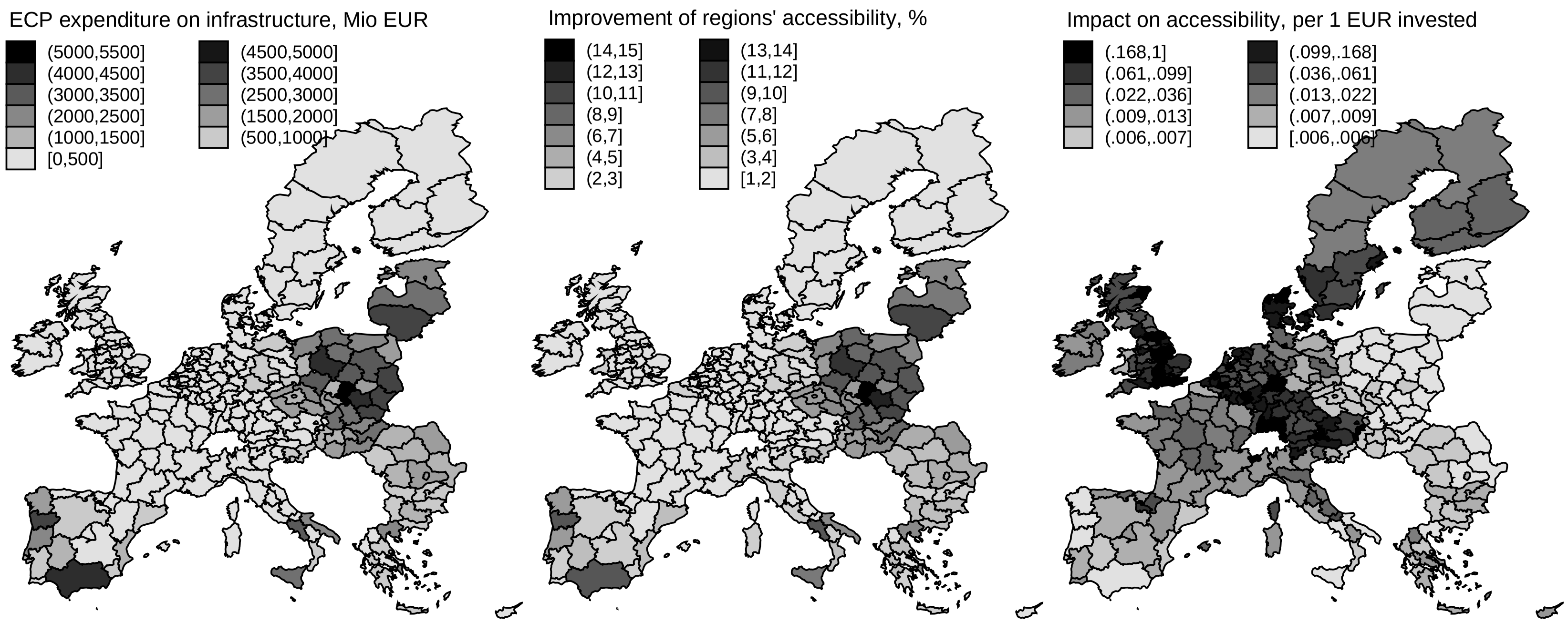

Figure 5: **INF scenario construction** (exogenous policy input into simulations). Left panel: EU Cohesion Policy's (ECP) expenditure on transport infrastructure in 2014-2020, Million EUR. Middle panel: Estimated improvement in regions' accessibility due to the ECP's investments in transport infrastructure in 2014-2020, changes in percent. Right panel: Estimated marginal improvement in regions' accessibility due to the ECP's investments in transport infrastructure in 2014-2020 per 1 Euro of investment. Middle panel represents the policy shock used as input in model simulations, left and right panels are reported only for background information. Source: Authors' estimations based on European Commission, DG REGIO (2013) data.

than for the less developed regions.[14]

5. Simulation results

5.1. RTDI vs. INF scenario

Simulation results – the ECP-induced GDP growth effects compared to the baseline – are presented in Figures 6 and 7.[15] Whereas Figure 6 maps the cumulative effects by 2025 of the entire 2014-2020 expenditures, Figure 7 plots the annual figures (average 2014-2020). The results reported in Figure 6 suggest that the impact of the ECP is heterogenous across EU regions. In particular, regions in the new EU Member States and southern EU would benefit substantially from the ECP investment in research, technological development and innovation (RTDI) (left panel) and transport infrastructure (INF) (right panel). In both scenarios, the policy-induced GDP growth effects vary between 0.01 and 2.75 percent of the baseline, though the pattern is different across the two scenarios.

The simulation results also show that the maximum estimated increase in productivity (as reported in Figure 3) is larger than the maximum simulated GDP increase (as reported in Figure 6). In Figure 3 there are only two regions with productivity increase above 4% (PL31 and PL32), and there are only three regions with productivity increase between 3 and 4% of the baseline (PL34, PL35 and PL62). In 12 other regions the productivity increases between 2 and 3%; in 26 regions it ends up between 1 and 2% of the baseline. In the vast majority of regions (224), the estimated productivity increase is between 0 and 1%. In contrast, the simulated GDP increase is more homogenous across regions (see Figure 6). These results are interesting, as they show how, through the inter-regional linkages, the positive growth effects of the ECP in the less developed regions diffuses to regions that were not (or were less) directly affected by the policy support. Knowledge spillovers play a particularly important role in determining the spatial distribution of the R&D impacts.

[14]For further details and assumptions of transport infrastructure scenario construction see Kancs (2013).

[15]All simulation results presented in this sections were performed with the RHOMOLO model, which was calibrated to 2007 base year data. See https://ec.europa.eu/jrc/rhomolo for the latest version of the RHOMOLO model and base year data.

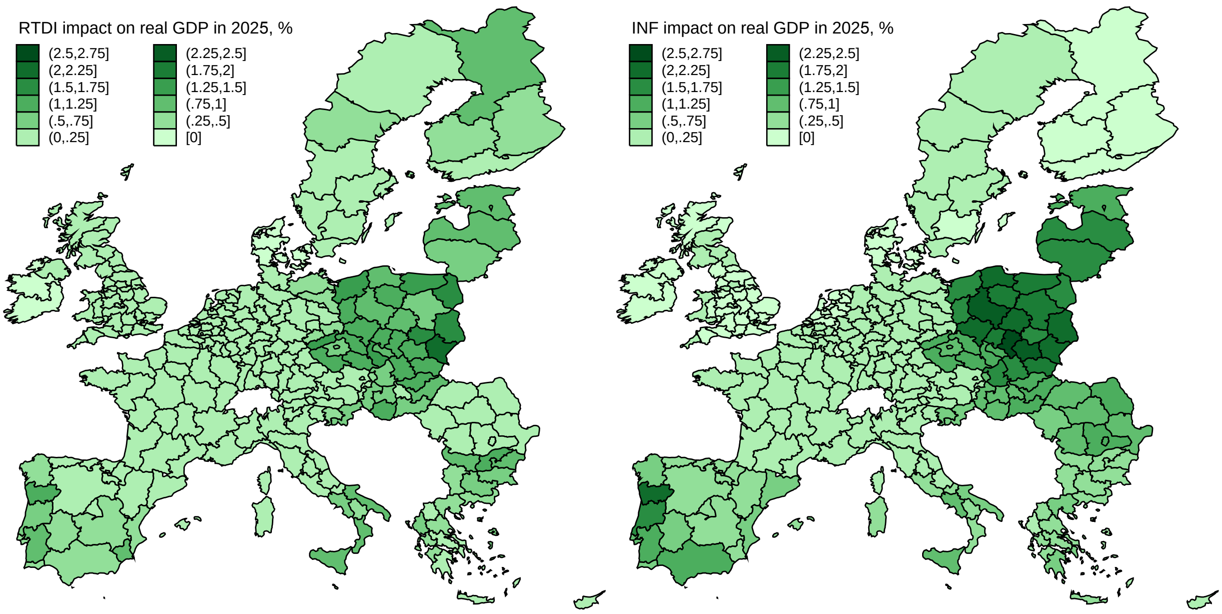

Figure 6: **Simulation results**. Left panel: RTDI impact on real GDP in 2025. Right panel: INF impact on real GDP in 2025. Notes: Percentage changes from the baseline. Source: Authors' simulations with the RHOMOLO model.

Figure 7 compares the ECP investments and GDP impacts of these investments in the less developed regions with those in the more developed regions. In all four diagrams, the X axis measures the development level of regions (log GDP per capita): less developed regions are on the left, and more developed regions are on the right. The Y axis measures the share of ECP in the regions' GDP: the left panels capture the share of the ECP investment in regions' GDP (RTDI top, INF bottom); the right panels capture the change in real GDP due to ECP investments (RTDI top, INF bottom). In other words, horizontally Figure 7 compares policy input to policy output, whereas vertically Figure 7 compares the RTDI scenario with the INF scenario. If the relationship between policy input and output would be linear, then the size of the squares/circles and their location on the vertical axis would be identical between the left and the right panels.

This, however, does not seem to be the case in our simulation results. The vertical position of the plots in Figure 7 suggests that, on average, the more developed regions (circles on the right) receive a lower share of ECP investments in RTDI and INF in terms of their GDP than the less developed regions (squares on the left). The relative size of the squares/circles (which is proportional to the size of the investment in million euros) shows that the less developed regions receive not only a higher share in terms of GDP, but also higher amounts in euros for their investments in RTDI and INF (squares on the left are considerably larger than circles on the right).

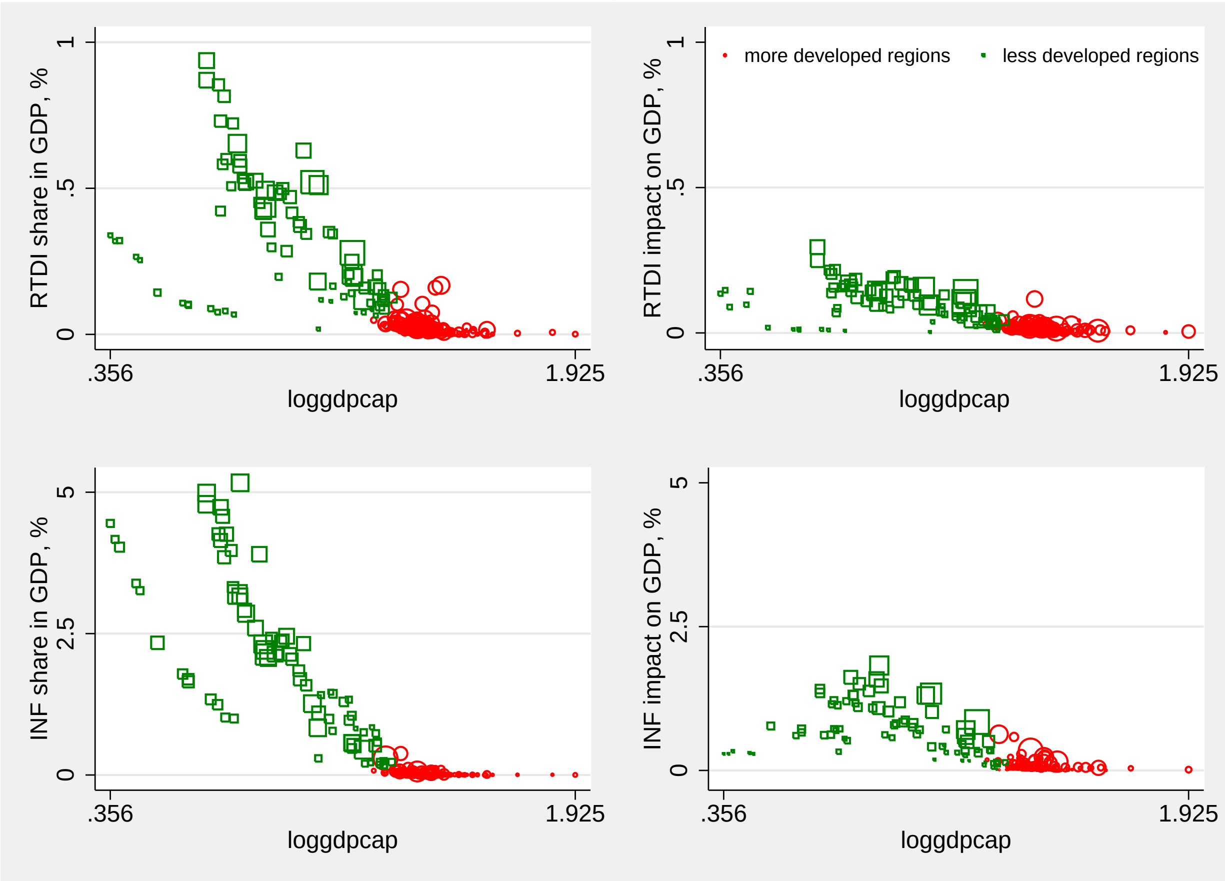

Figure 7: **Simulation results**. Left panels: Policy input (RTDI top, INF bottom) into the EU regions. Right panels: Policy effect (RTDI top, INF bottom) in the EU regions. Size of the squares/circles represents millions Euros (policy input left panels, policy impact right panels). Source: Authors' simulations with the RHOMOLO model.

The annual ECP investments in research, technological development and innovation range from 0 to around 1 percent of the regions' GDP (top-left panel). The return to ECP investment in RTDI ranges from 0 to around 0.25 percent (top-right panel). The relative size of the squares/circles and their location on the vertical axis shows that the impact of the ECP investment in RTDI is non-linear in the level of regions' development. In the case of the INF scenario, the annual ECP investment ranges from 0 and 5 percent (bottom-left panel), showing a significant variation between EU regions. The bottom-right panel in Figure 7 depicts the impact of INF investment on GDP. In contrast to the RTDI scenario, there appears to be an inverse U-shaped relationship between the returns to INF investment and the level of regions' development. In the short run, this can be explained by the necessary absorptive capacity, which regions must possess in order to efficiently use the ECP investments. As the absorptive capacity increases with the level of the regions' development, the more developed regions are able to use the ECP funds more efficiently.[16]

In terms of the investment multiplier effect (compare the right panels with the left panels in Figure 7), the results are exactly as those in the QUEST model because, for the purpose of the present study, RHOMOLO was calibrated to QUEST. For the whole EU, the research, technological development and innovation policies have an investment multiplier of 0.21. The investment multiplier of transport infrastructure policies is somewhat lower at 0.15. However, as described above, there is a substantial variation among regions. In some less developed regions, where the absorptive capacity is sufficient, the investment multiplier is higher than 0.50, implying that every invested euro in transport infrastructure increases GDP in the supported regions by at least 0.50 euro in the medium run (2025). In addition, given that the supply side effects accumulate over time, the long run gains to welfare are substantially higher, even when discounted over time, than in the QUEST model.

5.2. Decomposition and sensitivity analysis

What drives these differences in the impacts between EU regions? First, as shown in Figures 3 and 5, policy interventions and hence scenario inputs in simulations are differential across EU regions. Regions located in the Eastern and Southern parts of the EU are both the largest recipients of the ECP funds and the largest beneficiaries in terms of GDP growth.

Second, regions themselves are heterogeneous. For example: the relative importance of transport costs in the traded goods value differs significantly between regions; regions with higher initial transport costs benefit relatively

[16]Absorptive capacity is not modelled explicitly in RHOMOLO, however, it is assumed that there is a maximum of policy support that can be absorbed per year (0.5% of GDP). In addition, market imperfections, e.g. in labour and capital mobility, may lead to decreasing returns to public investment in the short run.

more than other regions. The structure of the regional economies also matters: 'non-treated' regions with a higher share of tradable goods (e.g. in manufacturing) benefit relatively more than regions with a lower share of tradeables (e.g. in services). Geography plays a role as well: the remote regions in RHOMOLO benefit less from border-crossing transport cost reductions than central regions.

Third, the endogenous channels of adjustment are multiple and the net effects are non-linear in the level of policy shock. In general equilibrium models, such as RHOMOLO and QUEST, a policy shock – an increase in TFP or a reduction of transport costs – triggers changes in the relative prices/costs. For example: the output price in one sector changes relative to the output price of another sector; the input price of one factor (e.g. labour), may change relative to the price of another factor (e.g. capital); the output or input price in one region may change relative to the output or input price in another region. Depending on which prices/costs change, relative to the prices/costs of competitors, the adjustments take place through different channels. The sectoral channel of adjustment; adjustments through factor supply and demand; the spatial channel of adjustment, etc.

In this section we present decomposition and sensitivity analysis results for a selected set of variables related to the spatial channel of adjustment. In RHOMOLO the spatial channel of adjustment works e.g. through the relocation of firms (and production factors) between regions, and is determined by two first order effects: (i) the market access effect (increase in firm output; decrease in average costs), and (ii) the price index effect (decrease in the cost of living; decrease in the cost of intermediate goods); and one second order effect: (iii) the market crowding effect (competition on input markets, competition on output markets). To decompose the aggregate effects, we run the above simulations (combined RTDI and INF) twice: first, all variables in RHOMOLO are endogenous (as above); and second, the selected variables are fixed exogenously at their base line value. The differences between the two sets of model runs are plotted in Figures 8-9.

On the output side, the market access effect is related to an increase in firm output (left panel in Figure 8). In RHOMOLO increasing firm productivity or reducing transport costs makes goods less expensive. A lower price of

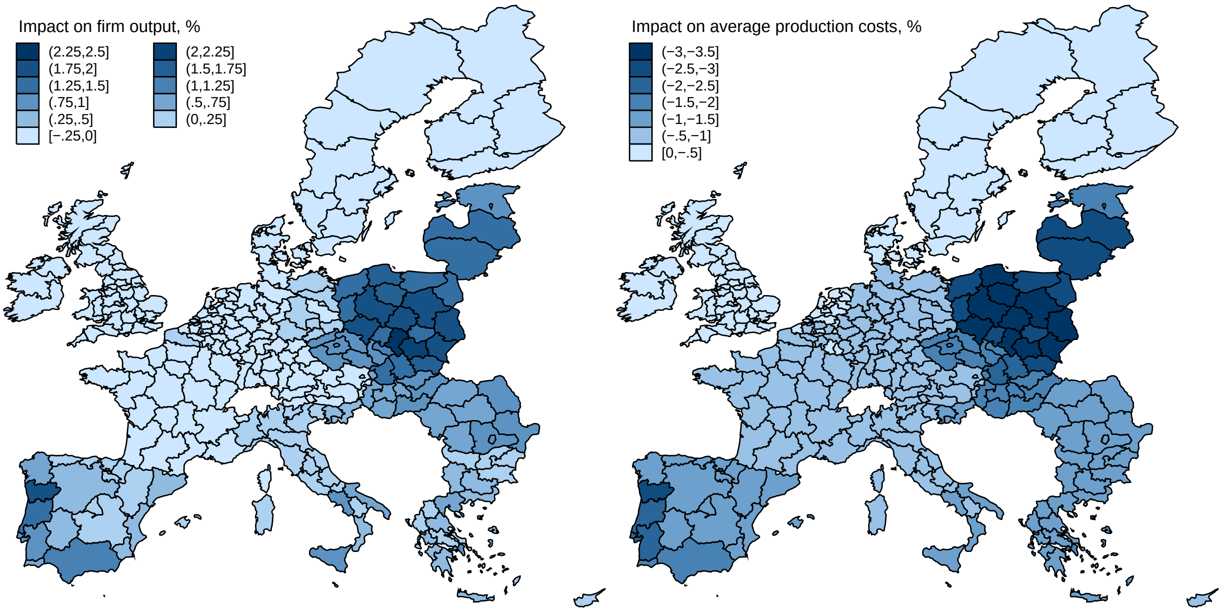

Figure 8: **Market access effect**. Left panel: RTDI and INF policy impact on firm output, percentage change. Right panel: RTDI and INF policy impact on average production costs, percentage change. Source: Authors' simulations with the RHOMOLO model.

goods allows households (and firms) to buy more goods, which implies higher demand, higher output and hence higher profits for firms. The left panel in Figure 8 confirms that firm output is increasing in all regions, particularly in the less developed regions. Higher growth in firm output in the less developed regions explains part of the higher GDP growth in these regions.

On the cost side, the market access effect is related to a decrease in average costs (right panel in Figure 8). In RHOMOLO, due to fixed production costs, higher output reduces the average production costs, and hence increases firm profitability. The right panel in Figure 8 confirms that the average production costs decrease in all regions, particularly in the less developed regions. Larger decreases in production costs in the less developed regions explain part of the higher GDP growth in these regions.

For consumers, the price index effect implies changes in the cost of living (left panel in Figure 9). In RHOMOLO lower transport costs reduce the price of traded goods, which implies that goods are sold at a lower price. The left panel in Figure 9 confirms that the consumer price index decreases in all regions, particularly in the less developed regions. Larger decreases in the cost of living in the less developed regions explain part of the higher GDP growth in these regions.

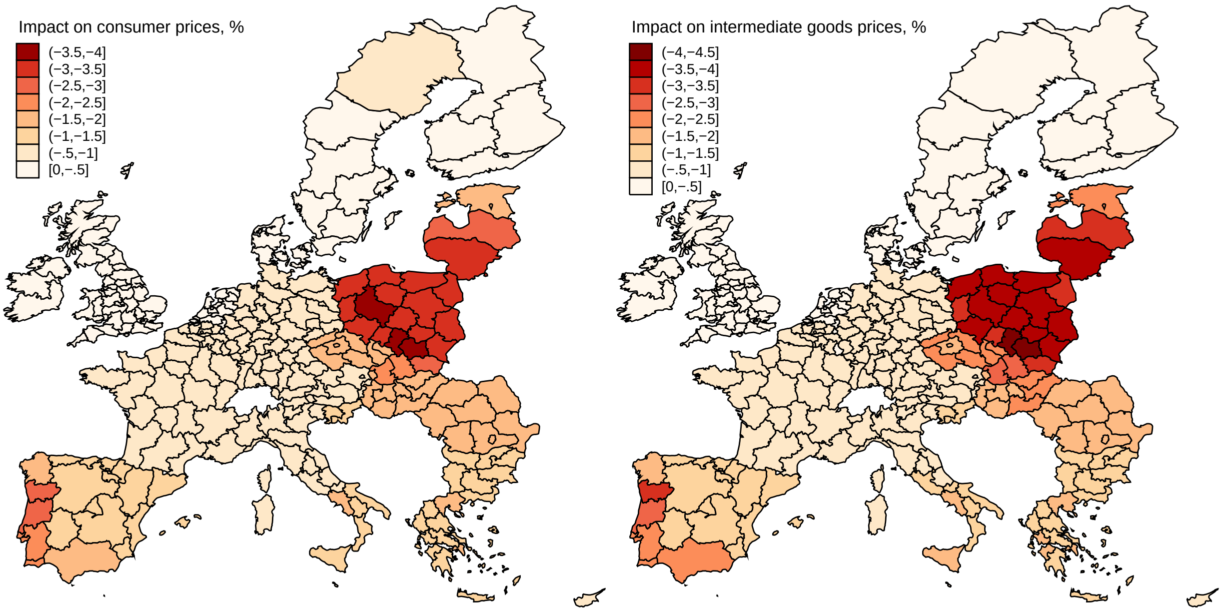

Figure 9: **Price index effect**. Left panel: RTDI and INF policy impact on consumer prices, percentage change. Right panel: RTDI and INF policy impact on intermediate goods prices, percentage change. Source: Authors' simulations with the RHOMOLO model.

For producers, the price index effect implies changes in the cost of intermediate goods (right panel in Figure 9). In RHOMOLO lower transport costs reduce the price of imported goods, which implies that intermediate goods are bought at a lower price. The right panel in Figure 9 confirms that the price index of intermediate inputs for producers of final demand goods decreases. Larger decrease in the cost of intermediate goods in the less developed regions explains part of the higher GDP growth in these regions.

Finally, the market crowding effect on input markets captures the fact that agglomeration of firms increases competition on local input markets, as a result of which firm profits decrease. In RHOMOLO more firms compete for a smaller pool of labour. The market crowding effect on output markets captures the fact that the agglomeration of firms increases competition on output markets, as a result of which profits decrease. More firms compete for a smaller share in the exports market.[17]

[17]Due to dimensionality issues, this effect is not shown graphically.

The decomposition and sensitivity analysis of our simulation results suggests that all key ingredients of the new economic geography theory, (i) the market access effect (increase in firm output; decrease in average costs), (ii) the price index effect (decrease in the cost of living; decrease in cost of intermediate goods); and (iii) the market crowding effect (competition on input markets, competition on output markets) are crucial for identifying the geographical distribution of the gains from economic integration. Hence, the role of spatial computable general equilibrium models, such as RHOMOLO, is particularly important when the spatial dimension of policy interventions matters, and can help to identify regions where policies can be expected to contribute most to prevent a further widening of economic disparities and prospects.

5.3. Limitations and future work

Several key assumptions need a closer examination when interpreting results of the presented simulations using the RHOMOLO model. First, it is assumed that all ECP policies are implemented according to the ex-ante time profile foreseen by the European Commission (2013). In reality, however, there are significant delays in policy implementation, and these delays will also vary significantly between Member States. The absorptive capacity of regions and the funds available for co-financing the ECP are two reasons for delays in the implementation of the ECP funds (Brandsma *et al.*, 2013). The implications of this assumption for the RHOMOLO simulations is that, in reality, the medium- and long-run results would be delayed, compared to the results presented above.

Second, the financing of the ECP through contributions to the EU budget is not explicitly modelled in the present study. In reality, however, as any other category of public expenditures, the ECP investments have to be financed through taxes. The increase in taxes for the purpose of financing the ECP investments partially offsets the positive growth impacts displayed by the simulation results. It is likely that the effect of financing reduces the positive impact in the Member States that make the largest contributions to the EU budget. In order to address this issue, the RHOMOLO model is calibrated to the macro-dynamics of the QUEST model, which accounts for all the taxes in a fully dynamic forward looking general equilibrium framework.

Another limitation of the recursively dynamic approach is in generating results over time. The main dynamics in RHOMOLO are the long-term effects of human, knowledge and physical capital accumulation, which continue after the funding has ended. While, inter-temporal optimisation and forward-looking expectations are at the basis of the decisions underlying the theoretical underpinning of DSGE models, such as QUEST, they are still not among the main features than are well captured in recursively dynamic models (Broecker and Korzhenevych, 2013). In order to address this issue, the present study combines RHOMOLO simulations with the fully dynamic QUEST model. The results show that cohesion policy support to the R&D investment would put the less developed regions as a group on a continuous track of closing the technology gap with more advanced regions.

Turning to limitations regarding the empirical implementation, a general problem of the adopted spatial computable general equilibrium approach is that almost all model data are used for calibration, whereas very little data is left for testing the model econometrically. Hence, the econometric estimation and testing of the RHOMOLO model are still open issues to be addressed in the future.

6. Concluding remarks

Regional development in the EU and regions of the Member States shows an uneven geographic pattern which shifts with time. European Cohesion Policy provides the means for partially offsetting the adverse effects of economic integration and for assisting the less developed regions. In negotiating the allocation of funds, and even in selecting the categories of investment to be supported, the Member States attempt to maximise the benefits of belonging to the single market. Politically, it is almost inevitable that the negotiations will focus on the expected direct effects and financial benefits and on the desired shifts in demand. From the EU point of view, however, the interest is much more on assessing how much in the long term the EU economy as a whole benefits from the advantages of the single market and on making sure that, while further opening the market, the development potential and innovation capacity of all regions is fully exploited, leaving no regions behind. For the purpose of being able to calculate and show the indirect and long-term effects of EU funding as well as the effects of EU policies at the regional level, this paper presents a spatial general equilibrium model in which the economies of all NUTS2 regions are linked through international trade, factor mobility and spatial knowledge spillovers.

Two simulation exercises with the RHOMOLO model highlight what is at stake. The first assumes that the support to research and innovation from the Structural and Cohesion Funds will allow the less developed regions to increase total factor productivity and reduce their distance to the technology frontier. This is based on micro-econometric evidence of the effect of R&D on total factor productivity and empirical evidence that domestic R&D will make it easier to absorb the knowledge from elsewhere and so help the catching up of lagging regions. The model allows for differences between sectors, and for shifts in the sectoral composition of production in the regions, which typically depend on the extent to which the gains in productivity are translated into competitive advantages.

In the second exercise, the reduction in transport costs resulting from the investments in infrastructure financed with contributions from the Structural and Cohesion Funds are carefully assigned to the regions and to all bilateral connections between them. Even though the largest part of the funding in the category of infrastructure is directed towards the Member States that joined the EU in the past decade, it can be shown that the investments have positive effects on the more central regions as well, precisely because they benefit from improved connections with so many of the regions to which the funds are allocated. This reinforces the point that, although with the enhanced mobility of capital and firms it may be difficult to simulate where the demand and shares of profits will end up, it could in principle be possible to find a redistribution of the benefits of greater economic integration that leaves all regions better off.

The results of the decomposition and sensitivity analysis suggests that, without spatial linkages and knowledge spillovers, there would be little effect on the non-supported (less supported) regions in the long term. Our results also suggest that, given the free mobility of capital within the single EU market, it is difficult to pin down where the demand resulting from the availability and use of EU funding will end up, despite the attempts to do so is made in the decomposition and sensitivity analysis. This does not take away that shifts in demand play a major role in the agglomeration process.

As a conclusion, from a policy point of view, it should be stressed that the availability of Structural and Cohesion Funds enables individual regions to develop their capacity for improving both productivity and the standard of living. The closer the investments are directed at remedying the structural impediments and removing the bottlenecks to regional development, the greater will be the potential for reaping the benefits of economic integration. The strategic choices of the Member States and regions are increasingly scrutinised and the model presented in this paper may help to cope with the interactions and show which scenarios of public investment support would be most beneficial for the EU economy.

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Table 3: RTDI scenario construction: ECP expenditure on RTDI in 2014-2020 (Million Euro) and the estimated impact in regions' productivity (percent).

Region	EUR	TFP	Region	EUR	TFP	Region	EUR	TFP	Region	EUR	TFP
AT11	23.2	0.118	DEC0	50.2	0.120	GR25	50.5	0.180	PT11*	1486.7	2.219
AT12	69.0	0.050	DED1	269.6	0.626	GR30	199.4	0.118	PT15	52.4	0.528
AT13	6.5	0.004	DED2	294.0	0.775	GR41	15.6	1.450	PT16*	977.2	1.113
AT21	51.7	0.150	DED3	156.4	0.496	GR42	3.6	0.094	PT17	134.2	0.144
AT22	94.7	0.108	DEE0	373.5	0.403	GR43	49.1	0.152	PT18*	234.6	1.941
AT31	63.4	0.053	DEF0	83.2	0.107	HU10	86.3	0.099	PT20*	24.2	1.345
AT32	6.5	0.014	DEG0	268.9	0.036	HU21*	182.4	0.979	PT30	23.6	0.122
AT33	14.3	0.036	DK01	34.9	0.013	HU22*	115.0	0.817	RO11*	82.5	0.189
AT34	9.1	0.010	DK02	22.2	0.033	HU23*	199.6	2.833	RO12*	69.7	0.144
BE10	16.4	0.015	DK03	30.3	0.019	HU31*	276.4	2.658	RO21*	121.9	0.316
BE21	24.5	0.021	DK04	27.9	0.018	HU32*	240.5	2.287	RO22*	84.6	0.206
BE22	33.1	0.083	DK05	13.3	0.009	HU33*	316.4	0.864	RO31*	97.0	0.131
BE23	13.4	0.017	EE00*	600.6	1.981	IE01	46.3	0.025	RO32	31.8	0.023
BE24	11.2	0.016	ES11	550.9	1.085	IE02	152.2	0.024	RO41*	68.8	0.186
BE25	20.2	0.041	ES12	78.5	0.304	ITC1	193.8	0.282	RO42*	54.5	0.086
BE31	9.9	0.033	ES13	85.5	0.287	ITC2	5.8	0.080	SE11	7.0	0.002
BE32	95.8	0.287	ES21	155.6	0.173	ITC3	89.4	0.065	SE12	46.3	0.053
BE33	40.6	0.166	ES22	23.3	0.103	ITC4	138.4	0.031	SE21	26.6	0.048
BE34	12.0	0.211	ES23	13.5	0.081	ITD1	7.0	0.038	SE22	8.1	0.008
BE35	18.2	0.017	ES24	56.6	0.043	ITD2	3.9	0.006	SE23	29.2	0.026
BG31*	50.0	1.798	ES30	99.7	0.022	ITD3	134.6	0.050	SE31	119.6	0.330
BG32*	49.7	2.001	ES41	178.8	0.251	ITD4	51.8	0.064	SE32	117.8	0.736
BG33*	50.8	1.923	ES42	356.2	0.849	ITD5	64.8	0.024	SE33	177.5	0.190
BG34*	57.6	0.929	ES43*	225.2	0.484	ITE1	164.7	0.131	SI01*	329.0	0.842
BG41*	66.3	0.557	ES51	348.7	0.110	ITE2	75.0	0.220	SI02	241.9	0.468
BG42*	84.4	0.938	ES52	494.2	0.400	ITE3	74.5	0.076	SK01	142.9	0.322
CY00	54.2	0.178	ES53	30.2	0.049	ITE4	180.0	0.108	SK02*	331.2	0.850
CZ01	30.5	0.043	ES61	1078.4	0.847	ITF1	49.6	0.301	SK03*	309.0	1.925
CZ02*	297.3	0.711	ES62	173.0	2.374	ITF2	19.5	0.140	SK04*	410.6	1.608
CZ03*	314.3	1.734	ES63	3.9	0.000	ITF3*	1681.2	1.640	UKC1	95.9	0.219
CZ04*	325.3	2.168	ES64	6.7	0.000	ITF4*	835.6	2.651	UKC2	122.9	0.536
CZ05*	447.5	1.854	ES70	319.8	0.354	ITF5*	37.8	0.409	UKD1	16.9	0.069
CZ06*	424.5	1.683	FI13	109.3	0.258	ITF6*	519.8	1.896	UKD2	23.8	0.022
CZ07*	371.0	2.281	FI18	52.9	0.035	ITG1*	1068.9	1.963	UKD3	136.4	0.114
CZ08*	339.8	0.766	FI19	70.4	0.156	ITG2	62.1	0.025	UKD4	71.6	0.095
DE11	14.6	0.005	FI1A	120.4	0.501	LT00*	882.8	1.491	UKD5	88.8	0.245
DE12	10.5	0.006	FI20	1.2	0.010	LU00	16.6	0.018	UKE1	31.2	0.075
DE13	8.7	0.008	FR10	29.9	0.004	LV00*	632.0	1.476	UKE2	11.8	0.026
DE14	7.0	0.004	FR21	80.9	0.146	MT00	39.2	0.395	UKE3	50.0	0.057
DE21	33.1	0.015	FR22	112.7	0.149	NL11	22.7	0.046	UKE4	91.7	0.067
DE22	15.2	0.027	FR23	115.4	0.124	NL12	31.6	0.118	UKF1	63.2	0.045
DE23	11.6	0.019	FR24	82.5	0.095	NL13	23.6	0.096	UKF2	59.7	0.079
DE24	13.1	0.020	FR25	85.3	0.183	NL21	20.2	0.029	UKF3	42.8	0.107
DE25	21.2	0.021	FR26	58.3	0.071	NL22	28.8	0.033	UKG1	29.0	0.040
DE26	15.3	0.018	FR30	268.0	0.225	NL23	11.1	0.043	UKG2	67.9	0.063
DE27	25.0	0.020	FR41	120.0	0.187	NL31	7.9	0.005	UKG3	161.5	0.092
DE30	269.7	0.339	FR42	31.8	0.064	NL32	15.0	0.007	UKH1	19.8	0.015
DE41	149.0	0.667	FR43	51.6	0.087	NL33	24.3	0.012	UKH2	11.5	0.008
DE42	38.8	0.126	FR51	150.5	0.116	NL34	1.9	0.005	UKH3	17.4	0.005
DE50	40.2	0.065	FR52	100.3	0.121	NL41	25.4	0.014	UKI1	14.6	0.004
DE60	4.6	0.002	FR53	64.6	0.095	NL42	16.6	0.008	UKI2	19.6	0.006
DE71	32.1	0.014	FR61	207.9	0.226	PL11*	612.7	1.009	UKJ1	1.3	0.001
DE72	9.0	0.016	FR62	147.7	0.302	PL12	749.7	0.688	UKJ2	2.6	0.002
DE73	12.2	0.018	FR63	31.4	0.037	PL21*	915.1	2.211	UKJ3	2.2	0.002
DE80	212.5	0.789	FR71	117.2	0.075	PL22*	1076.1	1.432	UKJ4	2.5	0.002
DE91	80.1	0.097	FR72	55.2	0.110	PL31*	638.9	4.276	UKK1	17.4	0.013
DE92	98.9	0.117	FR81	141.0	0.184	PL32*	662.4	4.970	UKK2	10.4	0.037
DE93	56.6	0.101	FR82	166.9	0.368	PL33*	399.8	3.263	UKK3*	83.4	0.642
DE94	80.7	0.067	FR83	20.0	0.006	PL34*	378.1	3.292	UKK4	18.9	0.059
DEA1	130.5	0.038	GR11*	89.7	1.066	PL41*	746.0	1.350	UKL1*	380.9	0.716
DEA2	67.2	0.031	GR12*	167.5	0.590	PL42*	390.3	2.850	UKL2	53.4	0.077
DEA3	46.6	0.040	GR13	11.2	0.180	PL43*	237.9	1.802	UKM2	81.0	0.116
DEA4	31.1	0.026	GR14*	107.6	0.877	PL51*	562.3	1.460	UKM3	210.0	0.376
DEA5	103.0	0.058	GR21*	63.5	1.879	PL52*	311.1	1.922	UKM5	14.8	0.209
DEB1	34.1	0.071	GR22	23.1	0.921	PL61*	516.3	2.168	UKM6	37.9	0.477
DEB2	7.7	0.027	GR23*	92.9	0.922	PL62*	387.0	3.042	UKN0	98.5	0.016
DEB3	39.5	0.042	GR24	20.7	0.135	PL63*	570.9	0.762			

Source: Authors' estimates based on the European Commission (2013) data. Notes: Aggregate Cohesion Policy expenditure on RTDI for the entire 2014-2020 period in Million EUR, TFP: estimated increase in total factor productivity in percent. * indicates Less Developed Regions.

Table 4: INF scenario construction: ECP expenditure on INF in 2014-2020 (Million Euro) and the estimated impact in regions' accessibility (percent).

Region	EUR	Tcost	Region	EUR	Tcost	Region	EUR	Tcost	Region	EUR	Tcost
AT11	0.7	1.664	DEC0	2.6	1.506	GR25	51.0	2.507	PT11*	359.6	9.045
AT12	3.9	1.751	DED1	49.0	2.810	GR30	232.1	6.683	PT15	17.9	1.655
AT13	2.1	1.773	DED2	53.4	2.930	GR41	17.7	1.675	PT16*	210.3	5.820
AT21	1.1	1.552	DED3	26.8	2.236	GR42	16.2	1.659	PT17	111.5	3.668
AT22	2.0	1.641	DEE0	57.2	2.964	GR43	55.5	2.464	PT18*	53.2	2.418
AT31	1.7	1.612	DEF0	6.7	1.622	HU10	161.0	5.602	PT20*	31.4	1.587
AT32	0.7	1.549	DEG0	50.1	2.765	HU21*	148.1	5.301	PT30	30.7	1.638
AT33	1.9	1.536	DK01	1.9	1.470	HU22*	124.4	4.693	RO11*	126.0	4.119
AT34	0.6	1.493	DK02	1.6	1.452	HU23*	156.2	5.331	RO12*	114.1	3.782
BE10	1.3	1.455	DK03	1.6	1.478	HU31*	217.0	6.873	RO21*	199.6	5.538
BE21	2.2	1.480	DK04	1.5	1.454	HU32*	269.7	8.046	RO22*	139.4	4.220
BE22	2.9	1.490	DK05	0.7	1.420	HU33*	224.5	6.947	RO31*	160.0	4.711
BE23	1.1	1.431	EE00*	221.9	6.196	IE01	15.3	1.333	RO32	52.1	2.507
BE24	0.5	1.425	ES11	176.3	5.122	IE02	9.1	1.226	RO41*	114.5	3.801
BE25	1.6	1.434	ES12	25.7	1.905	ITC1	32.0	2.174	RO42*	79.8	3.120
BE31	0.8	1.452	ES13	8.6	1.529	ITC2	1.0	1.460	SE11	1.3	1.198
BE32	7.3	1.583	ES21	22.7	1.860	ITC3	10.0	1.644	SE12	2.6	1.215
BE33	3.5	1.512	ES22	4.9	1.457	ITC4	22.0	1.951	SE21	3.5	1.229
BE34	1.1	1.461	ES23	2.6	1.411	ITD1	2.8	1.548	SE22	2.4	1.261
BE35	1.5	1.461	ES24	24.5	1.886	ITD2	1.3	1.505	SE23	2.4	1.240
BG31*	65.6	2.943	ES30	28.4	1.971	ITD3	22.9	2.016	SE31	8.8	1.299
BG32*	64.9	2.904	ES41	55.4	2.557	ITD4	6.9	1.651	SE32	7.8	1.245
BG33*	65.3	2.895	ES42	45.0	2.308	ITD5	8.4	1.627	SE33	10.5	1.251
BG34*	73.5	3.050	ES43*	106.2	3.640	ITE1	27.4	2.045	SI01*	93.2	3.700
BG41*	84.0	3.322	ES51	78.3	3.105	ITE2	9.0	1.647	SI02	68.8	3.110
BG42*	105.9	3.781	ES52	105.5	3.645	ITE3	10.3	1.664	SK01	35.1	2.569
CY00	23.7	1.673	ES53	7.6	1.452	ITE4	41.4	2.353	SK02*	285.3	8.708
CZ01	69.1	3.737	ES61	407.3	9.936	ITF1	7.5	1.594	SK03*	267.9	8.227
CZ02*	137.0	5.381	ES62	57.2	2.580	ITF2	3.0	1.493	SK04*	356.8	10.222
CZ03*	150.9	5.436	ES63	1.9	1.335	ITF3*	339.7	9.023	UKC1	5.1	1.465
CZ04*	160.0	5.703	ES64	3.1	1.291	ITF4*	223.4	6.389	UKC2	6.5	1.492
CZ05*	203.2	6.780	ES70	122.8	3.272	ITF5*	30.3	2.113	UKD1	1.0	1.356
CZ06*	193.7	6.507	FI13	6.8	1.234	ITF6*	97.7	3.520	UKD2	1.4	1.394
CZ07*	176.8	6.152	FI18	5.2	1.252	ITG1*	297.5	7.782	UKD3	7.9	1.555
CZ08*	167.3	5.989	FI19	6.2	1.240	ITG2	33.3	2.054	UKD4	4.2	1.451
DE11	1.0	1.486	FI1A	7.0	1.200	LT00*	396.5	10.233	UKD5	4.8	1.474
DE12	0.9	1.460	FI20	0.1	1.126	LU00	1.2	1.199	UKE1	1.6	1.398
DE13	1.0	1.458	FR10	3.8	1.227	LV00*	278.9	7.445	UKE2	0.6	1.369
DE14	0.6	1.473	FR21	9.1	1.370	MT00	47.1	1.907	UKE3	2.2	1.418
DE21	4.2	1.591	FR22	11.2	1.403	NL11	1.2	1.464	UKE4	4.7	1.472
DE22	2.2	1.596	FR23	14.4	1.454	NL12	1.7	1.469	UKF1	0.7	1.386
DE23	2.1	1.592	FR24	5.6	1.254	NL13	1.3	1.479	UKF2	0.7	1.396
DE24	2.0	1.571	FR25	7.3	1.294	NL21	2.8	1.529	UKF3	0.5	1.382
DE25	2.6	1.569	FR26	10.9	1.390	NL22	4.0	1.536	UKG1	1.8	1.415
DE26	1.8	1.526	FR30	38.5	2.025	NL23	1.4	1.478	UKG2	4.1	1.468
DE27	3.5	1.557	FR41	16.8	1.555	NL31	0.9	1.469	UKG3	9.8	1.622
DE30	11.5	1.876	FR42	3.6	1.283	NL32	1.9	1.462	UKH1	2.8	1.454
DE41	29.6	2.252	FR43	4.9	1.290	NL33	3.3	1.492	UKH2	1.0	1.416
DE42	7.2	1.724	FR51	14.0	1.404	NL34	0.3	1.414	UKH3	2.7	1.465
DE50	1.0	1.496	FR52	18.9	1.482	NL41	2.9	1.491	UKI1	3.0	1.473
DE60	0.2	1.506	FR53	14.4	1.422	NL42	1.9	1.485	UKI2	4.0	1.502
DE71	2.7	1.523	FR61	21.7	1.555	PL11*	335.4	9.783	UKJ1	0.2	1.394
DE72	0.8	1.485	FR62	25.7	1.627	PL12	344.7	9.832	UKJ2	0.6	1.413
DE73	1.0	1.504	FR63	5.1	1.246	PL21*	447.6	12.453	UKJ3	0.6	1.402
DE80	50.4	2.705	FR71	19.8	1.556	PL22*	526.3	14.553	UKJ4	0.7	1.430
DE91	7.0	1.658	FR72	6.3	1.280	PL31*	351.4	9.849	UKK1	1.7	1.420
DE92	8.6	1.679	FR81	28.9	1.711	PL32*	352.5	9.955	UKK2	1.4	1.405
DE93	13.9	1.808	FR82	16.6	1.476	PL33*	189.0	6.273	UKK3*	16.3	1.737
DE94	6.9	1.595	FR83	2.6	1.166	PL34*	188.4	6.046	UKK4	2.9	1.425
DEA1	8.7	1.636	GR11*	77.9	3.148	PL41*	408.2	11.563	UKL1*	44.6	2.418
DEA2	4.8	1.541	GR12*	219.4	6.325	PL42*	221.1	6.947	UKL2	3.7	1.449
DEA3	3.1	1.508	GR13	14.9	1.770	PL43*	139.0	5.059	UKM2	4.6	1.419
DEA4	2.1	1.507	GR14*	80.2	3.210	PL51*	323.7	9.698	UKM3	15.2	1.667
DEA5	6.9	1.602	GR21*	47.2	2.464	PL52*	142.9	5.331	UKM5	0.8	1.310
DEB1	1.2	1.462	GR22	23.2	1.892	PL61*	283.7	8.456	UKM6	2.8	1.317
DEB2	0.5	1.438	GR23*	93.3	3.449	PL62*	219.8	6.780	UKN0	11.1	1.535
DEB3	1.7	1.481	GR24	24.8	1.956	PL63*	281.9	8.233			

Source: Authors' estimates based on the European Commission (2013) data. Notes: Aggregate Cohesion Policy expenditure on INF for the entire 2014-2020 period in Million EUR, Tcost: estimated reduction in transportation costs (weighted across all regions) in percent. * indicates Less Developed Regions.

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